Development of Satellite Based Sensor For Improved Measurement and Validation of Ionospheric Parameters

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LONG-TERM GOALS

Having ionospheric electron density distributions as a function of height, latitude, longitude, and time under different conditions is essential for scientific, technical, and operational purposes. A satellite-based, swept-frequency, HF sounder can obtain electron density profiles on a global scale. Under this STTR program we have developed a new-generation HF sounder that employs recent developments in technology, electronics, and processing capabilities. During phase II of the STTR program a laboratory prototype has been developed and tested. The system is ready to be adapted for flightworthy operation. It will provide global-scale electron density distributions, contours of fixed densities, maps of f0F2, hmax, etc. It will allow us to map irregularities, estimate anomalous propagation and conditions for ducting, determine angles of arrival, etc. It will also be able to perform various plasma diagnostics and, because of new flexibility, will be programmable from the ground to perform a variety of experiments in space. Need for such a system exists throughout the DoD and several civilian agencies. The specifications and relevant data for such a system are given in the Table below:

New-Generation Topside Sounder	
Frequency Range	1-30 MHz
Antenna	Crossed Dipoles (Transmitter) Four short dipoles (Receiver)
Transmit Power	10 to 200 Watts
Pulse Width	30-100 microsecs. (coded)
Sweep Speed	Variable (typical MHz/sec.)
Frame Time	Variable (typical 30 secs.)
Receiver	Software controlled
Receiver Dynamic Range	100 to 120 dB
Orbit	1500 to 2000 km
Inclination	65 degrees (to include HAARP) 45 degrees (for mid-latitude)
Data Storage	On-orbit Processing

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14. ABSTRACT
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Some of the novel features of the system include:

1. Software based design
2. Direction of arrival information
3. Synthetic aperture radar (SAR) type processing capabilities
4. Reconfiguration and flexible architecture with multi mission capabilities
5. Artificial intelligence and on-board processing.

OBJECTIVES

The overall objective of this STTR is to develop a suite of sensors for intercomparison, validation, and monitoring of the ionosphere. During Phase I we have identified scientific, technical, and operational needs. Based on these, we have concentrated on the design and development of a state-of-the-art topside sounder and two radio beacons for deployment in a small, inexpensive satellite that can be quickly designed, constructed, and launched. We defined system requirements, performed initial system design, and demonstrated real-time analysis capabilities. We also explored some of the mission elements, e.g., satellite bus, launch vehicle, and ground station.

During Phase II the objective is to perform a complete system and engineering design compatible with mission elements. For this we performed laboratory-based design and development of critical subsystems, demonstrated their capabilities, and, performed a systems integration and engineering design. A laboratory prototype unit has been designed, developed, and tested

During Phase III a space worthy system will be developed, integrated, and deployed. While we are waiting for the prototype unit to be adapted for operation in space, we are adapting the new generation sounder for ground based ionospheric sounding. The ground based sounder will provide a valuable advanced diagnostic for the ionosphere and plans are being made for a ground-based demonstration.

APPROACH

Several elements of the proposed topside sounder are novel, e.g., the software control, the on-board data processing, and the SAR mode. Some of the critical subsystems include:

- Sounder Hardware:
  - A DSP-based, software-controlled sounder with a coded waveform for improved performance at low power has been developed and a laboratory prototype built. It is based on Analog Devices AD2106X DSP processors. An advanced Radar Controller has been designed and built. The transmitter and receiver units have been designed and built.
  - This sounder control unit has been integrated with HF transmitter and receiver modules.

- The complete set of prototypes will be tested and demonstrated as an advanced ground-based digital ionosonde.

- Sounder Software:

  - The expert system and data analysis techniques demonstrated during Phase I have been improved.

  - The direction-finding algorithm has been developed.

  - Control sequences for the sounder have been developed.

  - The software will be tested on the ground-based prototype sounder and the data acquired with it.

- System Integration Plan and Engineering Design for the Mission Elements:

  - **Satellite System:** Other sensors, payload mass, power requirements, thermal requirements, pointing control and knowledge, on-board data reduction and compression, data storage, telemetry, command handling, interaction among sensors, redundancy, and environmental issues. Much of this will be determined by the selection of the appropriate satellite bus, e.g., buses made by Spectrum Astro, OSC, and Ball Aerospace.

  - **Launch System:** Launch vehicle, launch site, and certification. This will be affected by the payload, satellite bus, and desired orbit. Possibilities include Pegasus and Taurus, but consideration will not be limited to these.

  - **Ground Segments:** S-band versus X-band telemetry; one versus multiple ground stations; command structure and control; cross-links; data reduction, visualization, and archiving; and data distribution to end-users.

  - **Operational Plan:** Agencies, experimental priorities, and experimental plans.

WORK COMPLETED

The design of the sounder has been completed. A prototype model sounder has been developed. This prototype sounder will be tested as an advanced ground-based digital sounder. Plans are underway to field-test this advanced digital sounder and attempts are being made to commercialize this advanced digital sounder.

For commercialization, the ground-based digital sounder is being developed through internal resources. One novelty of the proposed approach is the software-based architecture. Various software modules are currently being generated. Utah State University personnel are investigating the satellite integration-related issues including antenna concepts.

RESULTS

The advanced digital sounder has been designed and built. Plans are underway for field-test and validation. The advanced sounder is unique in the sense that it outperforms any other digital sounder currently available. It has improved hardware and software capabilities. Plans are underway for commercialization. Detailed information may be obtained through www.cfrsi.com.

A paper was presented to the Ionosphere Effects Symposium (IES 99, appeared in Conference Proceedings). A detailed paper has been published in *Radio Science* (2001). Several presentation were made in various conferences such as PIERS (2000), Boston, MA.

IMPACT/APPLICATIONS

The proposed topside sounder will provide, as its primary measurement, the electron density distribution throughout most of the ionosphere, over most of the world, and under various solar and geophysical conditions. In its secondary measurement mode, the SAR mode, the sounder will provide a precise mapping of ionospheric irregularities. These observations will help us to:

- Provide electron densities and temperatures with which to validate numerous theoretical models of the ionosphere and to contribute to empirical models of the ionosphere

- Validate the density distributions derived from indirect techniques such as model inversion of satellite EUV measurements, tomographic inversion of total-electron content (TEC) or integrated column densities from ground-based observations of satellite beacons, etc.

- Provide inputs for assimilative ionospheric forecast models

- Improve performance of GPS systems because of measured plasmaspheric TEC

- Provide global mapping of ionospheric parameters, including electron densities and electron temperatures and, hence, plasma scale heights, for scientific research and operational systems

- Allow monitoring of seismo-ionospheric events for earthquakes, nuclear explosions, etc.

- Provide precise mapping of irregularities, tilts, and ionospheric anomalies, etc., thereby facilitating the understanding and prediction of scintillations and of other satellite communication issues

- Provide superior understanding of anomalous radio propagation through ducting, z-mode, around-the-world propagation, sporadic E, and scatter propagation

- Measure various plasma resonance near the spacecraft, provide precise measurements of magnetic fields, and diagnose the response of the topside ionosphere to HF modification experiments

- Provide a HF test-bed in the ionosphere that could be used to perform various sophisticated experiments

- Test technology that could be applied in diverse areas of communications, radar, space exploration, and related areas. It would provide direct observation of performance features for various communication systems.

- It would provide a basic version of space-based radar for exploration of ground conductivity, underground facilities, ground and near-ground targets, geophysics, ocean waves, etc.

TRANSITIONS

Direct observations of ionospheric features are crucial for various operations in communications, navigation, early warning, radar, etc. and will be especially invaluable for agencies like the Navy, Air Force, Army, NSA, CIA, DISA, and NOAA. The data will be of immense help to ionospheric scientists, radio and communications engineers, ionospheric modelers, radio amateurs, and the space-weather community. Ionospheric information and predictions made with the help of these data will be useful to GPS users, radio users, satellite users, and electric utilities as well. The data obtained with this system could be sold through insurance providers for satellite systems, electric utility providers, space weather analysts, radio communication and radio users, etc. A network of six such topside sounders would provide complete coverage for operational systems. Alternatively, the ionospheric data from one such topside sounder and from other sources could be assimilated into a new generation of physical models to provide global ionospheric predictions.

The advanced digital sounder will be tested and demonstrated as a ground based advanced digital HF diagnostic instrument and ionosonde. Once demonstrated the system will provide the most sophisticated system currently available. It will outperform any other HF diagnostics or digital sounder.

The new features of the advanced digital sounder are:

- Flexible operation, easy user interface, and various levels of interface allow standard to sophisticated programming at various levels. Many different experiments can be performed.

- Improved visualization tools allow various experiments to be performed in real time. Ease in de-bugging, data analysis.

- Various post-processing modules allow scientific analysis almost in real time.

- Internet and Web interfaces allow data storage and data dissemination. It also allows remote control and monitoring.

- Improved hardware features allow much wider ranges of sounding and receiving parameters compared to what are currently available. These include: frequency range, IPP range (1 to 30 ms, compared to 10 ms.), pulse width (10 microsecs to CW, compared to 20-30 microsecs), variable power to 1 kW, various waveforms (chirp, pulse, complementary code, barker code), polarization control, wider dynamic range, auto gain control, multiple antennas and multiple receiver configuration, SAR and interferrometric modes, direction of arrival, Doppler processing, etc.

- The system can be easily adapted by users to be used as a versatile HF diagnostics for numerous experiments on the ground and in space.

RELATED PROJECTS

The Center for Remote Sensing (CRS) is an R&D organization with strong ties to various universities and research laboratories throughout the world. The scientists and engineers at CRS have international reputations; CRS has completed or is working on more than 40 contracts for various agencies of the U.S. government during the past 12 years. Some of the relevant projects include:

- Digital Wideband Electromagnetic Sensors (DAAH01-98-C-R135)

- High Data Rate HF Communication (MDA972-97-C-0005)

- Improvements in HF Propagation using GPS (N00039-95-C-0024)

- Active Calibrator for TRMM Radar (NAS5-38010)

- Intelligent Receiver (NAS5-31928)

- Improved Propagation based on Physical Ionospheric Model (DAAB07-91-C-B014)

- Active Space Plasma Physics Program (NAS5-31195)

- Incoherent-Scatter Studies (NSF)

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